DarkSUSY

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Oskar Klein centre

Ways to search for dark matter

Accelerator searches

- LHC
- Rare decays
- ...

Direct searches

- Spin-independent scattering
- Spin-dependent scattering

Indirect searches

- Gamma rays from the galaxy
- Neutrinos from the Earth/Sun
- Antiprotons from the galactic halo
- Antideuterons from the galactic halo
- Positrons from the galactic halo
- Dark Stars
- ...

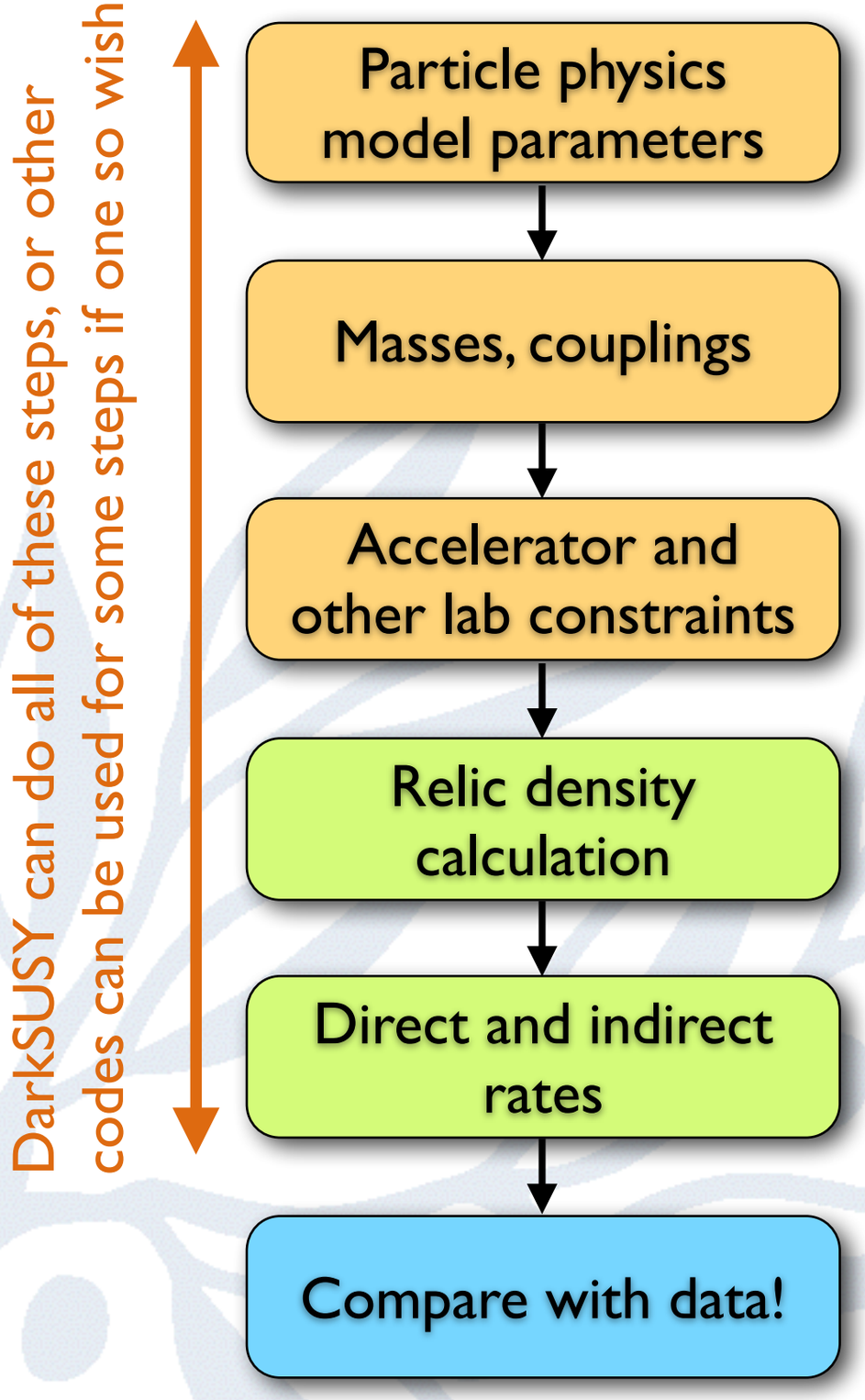
Need to treat all of these in a consistent manner, both regarding particle physics and astrophysics

Current version: 5.1.1

darksusy.org

Will not cover all of these...

Calculation flowchart



Parameters within a model, e.g. pMSSM, CMSSM, KK, etc

Spectrum calculator (e.g. RGE solver)

Direct searches, rare decays, precision measurements

Annihilation cross section calculator and Boltzmann equation solver

Rate calculator

Compare individual rates or perform global fits

Outline

- Introduction to and layout of DarkSUSY
- SUSY setup
- Accelerator constraints
- Relic density
- Direct detection
- Indirect detection:
  - gamma rays
  - charged cosmic rays
  - neutrinos (from the Sun/Earth)

Will focus on supersymmetric neutralinos as dark matter, but many results/ routines are applicable to any WIMP

Philosophy

- Modular structure (given the Fortran constraints...)
- Library of subroutines and functions
- Fast and accurate
- "Standard" Fortran - works on many platforms (g77 support dropped though)
- Flexible
- Version control (subversion) for precise version tagging

Current version: 5.1.1

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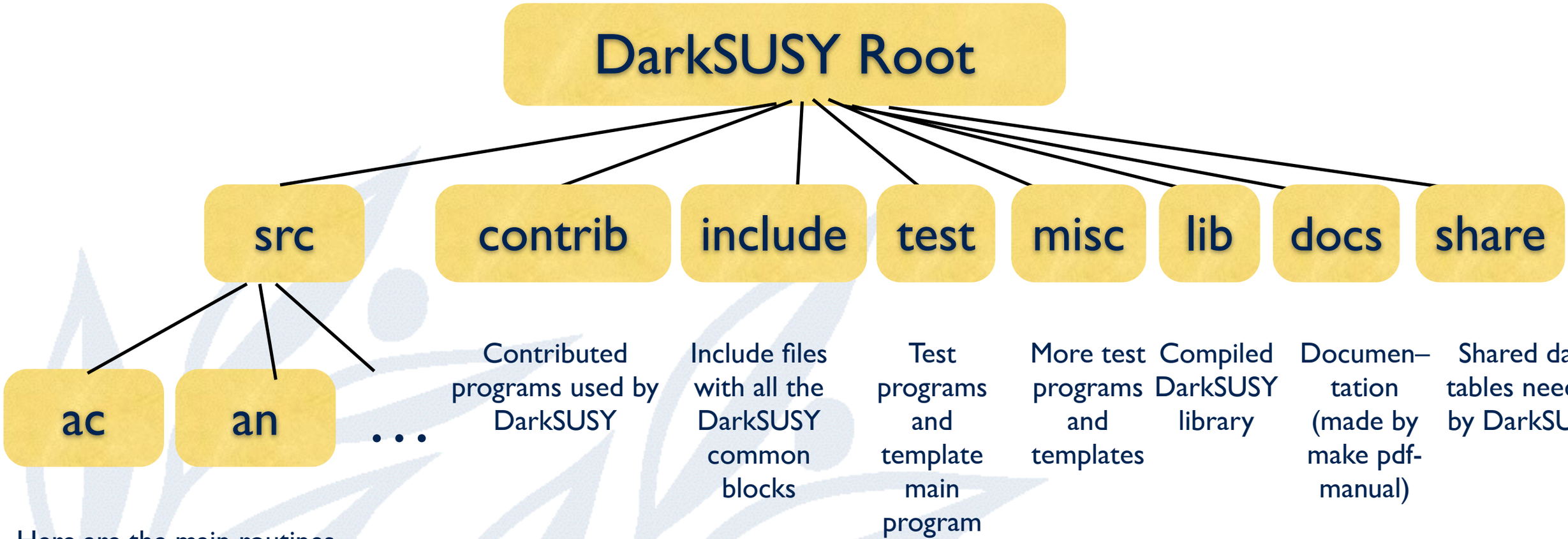
DarkSUSY 5 layout



Will come back to this at the end…

Compile and install

- To compile and install DarkSUSY, do

  ./configure [optional arguments]
  make

- Works on most platforms and with most compilers (gfortran, ifort, ...)

SUSY setup

- The full MSSM-124 has 124 free parameters (including complex phases)
- The goal is to be able to choose all of these arbitrarily
- We are not fully there yet, even if most things can be chosen quite arbitrarily in DarkSUSY
- Currently many matrices have to be real (but not necessarily diagonal)

Typical program

- `call dsinit`
- [make general settings]
- [determine your model parameters your way]
- `call dsgive_model` [or equivalent]
- `call dssusy` [or equivalent]- to set up DarkSUSY for that model
- [then calculate what you want]

See dsmain.f, dstest.f and dstest-isasugra.f in test/

*set routines

- Essentially all the packages in DarkSUSY have a corresponding *set routine that determines how those routines are going to be used, which parameter sets to use etc.

- As an example,
  call dshmset('default') chooses the default halo model (NFW)

- All these *set routines are called with the argument 'default' by dsinit, but can be changed later by the user.

Accelerator constraints and likelihoods

- DarkSUSY contains routines to check lab constraints (accelerators, rare decays etc)
- Also links to other codes like HiggsBounds and SuperIso
- We are working on going away from hard cuts to likelihoods when possible
- For example, in DarkSUSY 5.1 we include IceCube likelihoods
- To do this, we need publicly available data and background estimates/simulations

Relic density – DarkSUSY implementation

- We solve the Boltzmann equation,

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{\rm eff} v \rangle \left(n^2 - n_{\rm eq}^2 \right)$$

numerically, calculating the thermally averaged annihilation cross section,

$$\langle \sigma_{\rm eff} v \rangle = \frac{\int_0^\infty dp_{\rm eff} p_{\rm eff}^2 W_{\rm eff} K_1 \left(\frac{\sqrt{s}}{T} \right)}{m_1^4 T \left[\sum_i \frac{g_i}{g_1} \frac{m_i^2}{m_1^2} K_2 \left(\frac{m_i}{T} \right) \right]^2}$$

$$W_{\rm eff} = \sum_{ij} \frac{p_{ij}}{p_{11}} \frac{g_i g_j}{g_1^2} W_{ij} \quad ; \quad W_{ij} = 4 E_1 E_2 \sigma_{ij} v_{ij}$$

in every step using tabulated $W_{\rm eff}(p)$.

DarkSUSY can calculate $W_{\rm eff}$ for SUSY or you can supply your own and use DarkSUSY as a Boltzmann equation solver.

Direct detection

- Routines to calculate the spin-independent and spin-dependent scattering cross sections on protons and neutrons. These are most easily used to compare with experimental results.
- Also routines to calculate the differential rates on various targets including both spin-independent and spin-dependent form factors.
- Halo model and velocity distribution can be chosen arbitrarily
- Annual modulation signal can be calculated
- Different sets of form factors available

Indirect rates – Annihilation channels

- As we are very interested in trying to observe the annihilation products from dark matter annihilation, we need to investigate what they are. Some of the relevant are:

$$\chi\chi \rightarrow \begin{cases} b\bar{b} \\ t\bar{t} \\ \tau^-\tau^+ \\ W^-W^+ \\ Z^0Z^0 \\ \nu_\alpha\bar{\nu}_\alpha \\ H^\pm W^\pm \\ H_i^0 Z^0 \end{cases}$$

Note: ν final states are absent for neutralinos

- These will hadronize/decay and produce electrons, positrons, antiprotons, gamma rays, neutrinos etc
- As the neutralino is a Majorana fermion, the annihilation cross section to fermions go as

$$\sigma_{f\bar{f}} \propto \frac{m_f^2}{m_\chi^2}$$

which means that we will be dominated by the heavy fermions (b and t quarks).

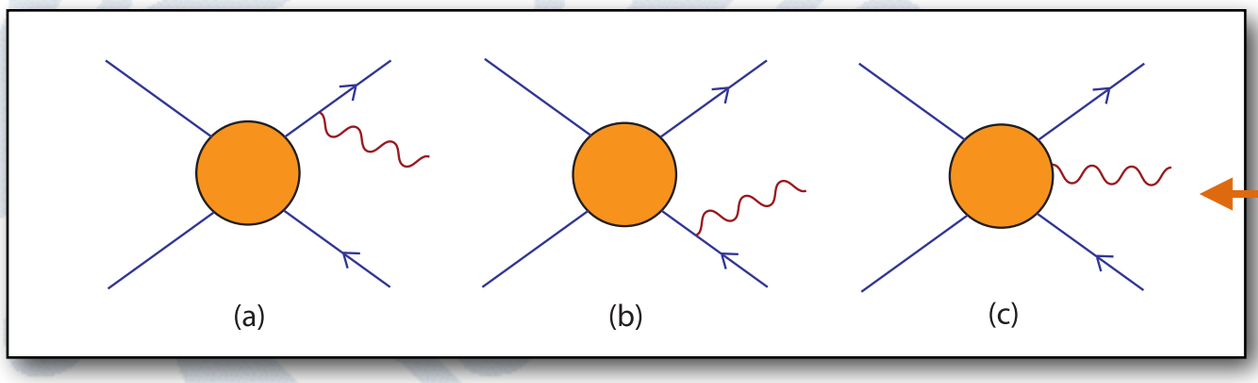
- Yield calculated with Pythia and tabulated for use by DarkSUSY (10 GeV – 10 TeV)
- Higgs bosons are let to decay in flight summing up the yields from the decay products

Gamma rays

- DarkSUSY includes generic WIMP routines to calculate gamma yields from WIMP annihilations
  - Based on Pythia simulations for WIMP masses between 10 GeV and 10 TeV

Works for any WIMP

  - Line signals
  - Internal Bremsstrahlung added separately

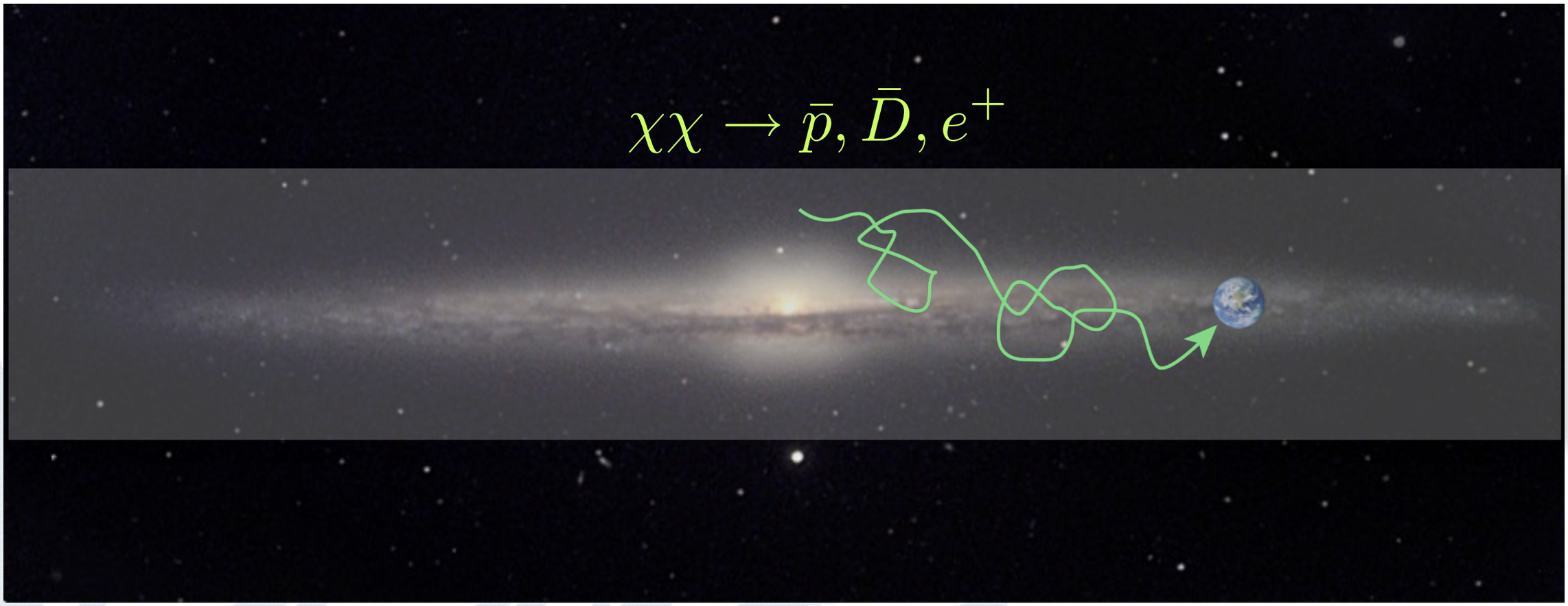


Virtual internal bremsstrahlung is model dependent!
SUSY calculation included.

Halo profiles

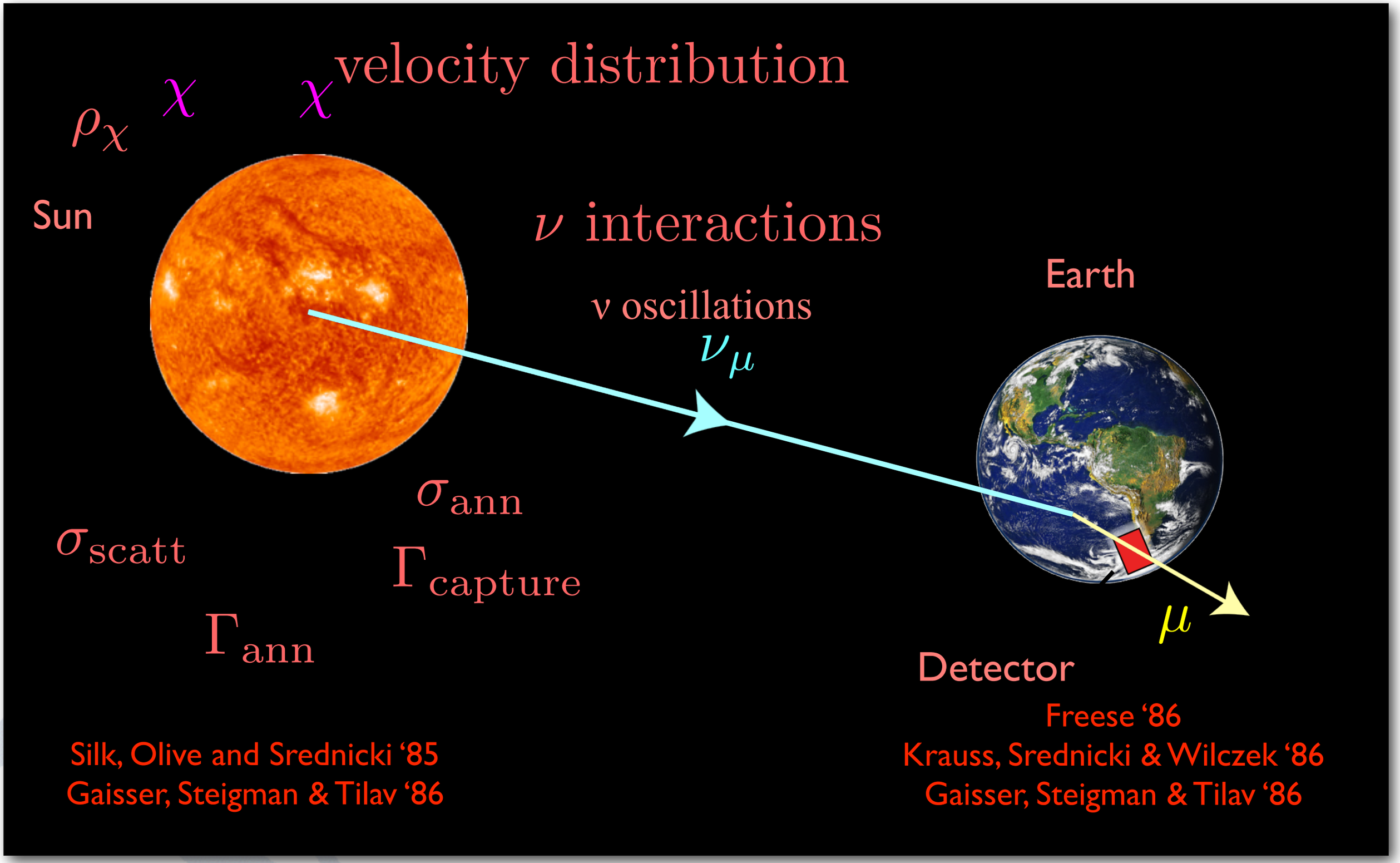
- Any spherically symmetric profile can be entered into DarkSUSY. Presets are available for
  - NFW
  - Moore
  - Burkert
  - Einasto
  - Adiabatically contracted profiles
  - Isothermal sphere
- In principle, a corresponding velocity distribution should be set simultaneously and DarkSUSY is set up to do this.
- Halo profiles are set with dshmset('name')

Charged cosmic rays – diffusion model



- Cylindrical diffusion model with free escape at the boundaries
- Energy losses on the interstellar medium (for antiprotons and antideuterons) or starlight and CMB (for positrons)
- Analytic expressions in DarkSUSY (new improved ones in coming DS 6)
- Interface to numerical codes exist

Neutrinos from the Earth/Sun



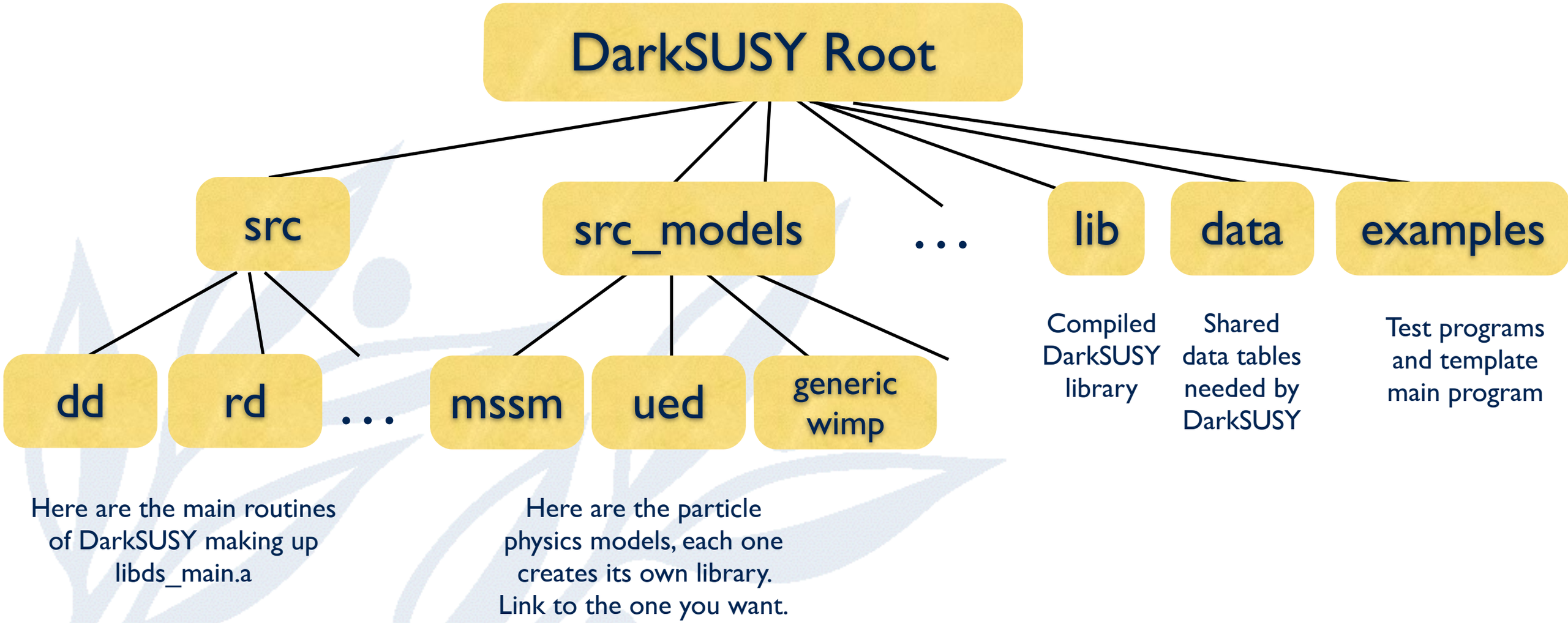
Neutrinos from the Earth/Sun

- Full numerical integration over solar radius, summing most relevant elements ("all" in coming DS 6)
- Full numerical integration over velocity distribution, no need to assume Maxwell-Boltzmann distribution
- In coming DS 6: full numerical integration over momentum transfer: arbitrary form factors can be used (do not need to be exponential)
- Interactions and oscillations in the Sun and to the detector simulated with WimpSim, results available as data tables in DarkSUSY.

DarkSUSY 6

- Major update (later this year)
  - Code made much more modular
  - Much easier to interface with different particle physics models
  - New refined halo annihilation and neutrino routines
  - Better solar models
  - Interface to Usine (?), Dragon
  - Interface to more specialized codes
  - At some point, maybe also DLHA = Dark matter Les Houches Accord
  - …

DarkSUSY 6 layout



- In DarkSUSY 6 you link to the particle physics model you want to use
- More clear division between particle physics model and general routines
  - General DS routines in src/
  - Particle physics model dependent routines in src_models/

And then we have the name…

- DarkSUSY has grown up to…
- DarkSUSAN
  = DarkSUSy And Not

Reference / download

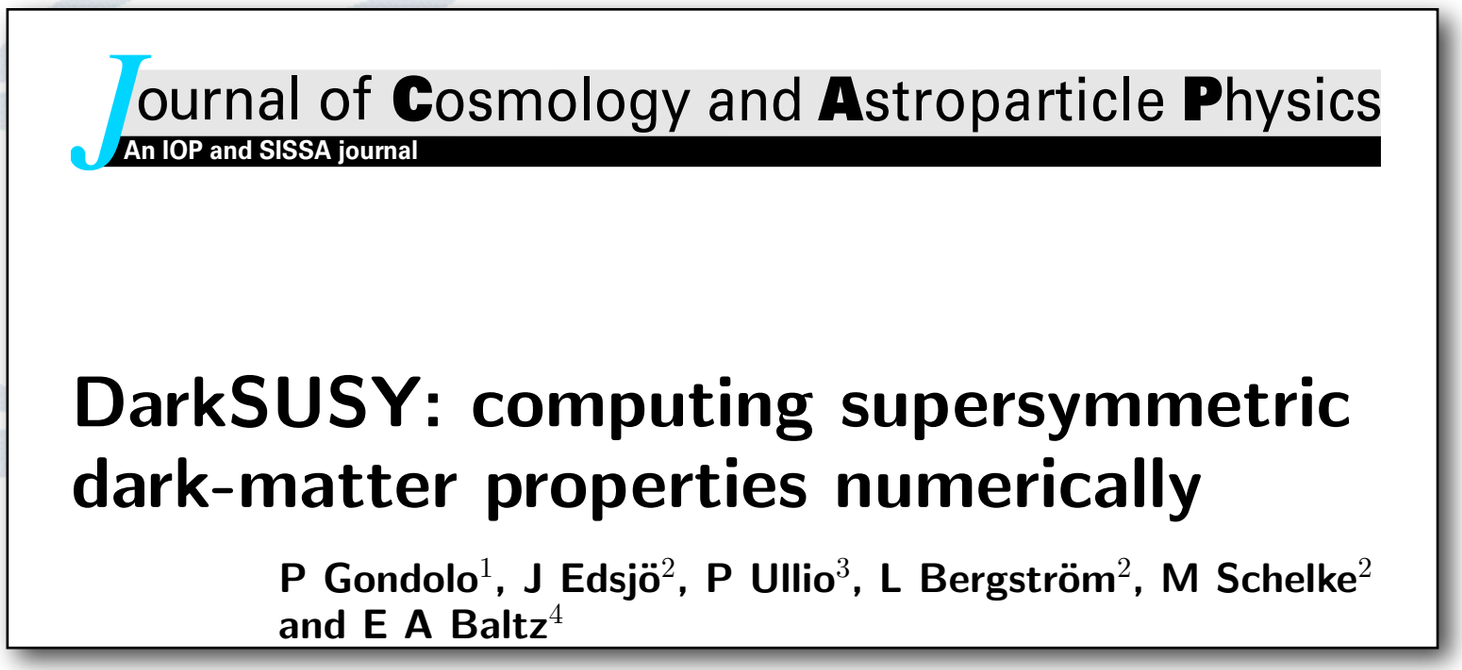
- DarkSUSY 5.1.1 is available at

  www.darksusy.org

- Long paper, describing DarkSUSY available as JCAP 06 (2004) 004 [astro-ph/0406204]

- Manual (pdf and html) available

WimpSim
for WIMP annihilations
in the Sun/Earth also
available.


Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

DarkSUSY: computing supersymmetric dark-matter properties numerically

P Gondolo[1], J Edsjö[2], P Ullio[3], L Bergström[2], M Schelke[2] and E A Baltz[4]

Conclusions

- DarkSUSY 5 publically available
- DarkSUSY 6 will be much more modular and include other improvements
- When comparing different signals, it is crucial to perform these calculations in a consistent framework, with e.g. a tool like DarkSUSY
- Need publicly available data!

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Thanks!

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